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A COMPARISON MEASUREMENT OF THE PHYSICAL PROPERTIES OF ROUND-ROBIN MATERIALS

Defence and Civil
INSTITUTE OF ENVIRONMENTAL MEDICINE

INSTITUT DE MEDECINE ENVIRONNEMENTALE
pour la défense

1133 Sheppard Avenue West, PO Box 2000, North York, Ontario, Canada M3M 3B9
Tel. (416) 635-2000 Fax. (416) 635-2104

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Brad Cain

Defence and Civil Institute of Environmental Medicine
1133 Sheppard Avenue West, P.O. Box 2000
North York, Ontario
Canada M3M 3B9

Abstract

A round-robin test of procedures for assessing certain textile properties has been proposed as part of a TTCP-PTP3 effort to facilitate the exchange of data between countries using different apparatuses. The objective of that study, Operating Assignment 9, is to determine whether values of thermal conductivity and water-vapour permeability of various fabrics are comparable when measured on two different apparatuses: the CORD Sweating Hot Plate (used by Australia and Canada) and the Hoenstein Sweating Hot Plate (used by the United Kingdom and the United States). Several fabric samples were submitted for independent testing by various nations. The work presented here is an alternative measure to the sweating hot plate approach for determining the relevant material properties. The two apparatuses used in this investigation were specifically designed to measure thermal conductivity and water-vapour permeability and should thus provide an accurate benchmark for comparison of the other methods.

Executive Summary

A round-robin test of procedures for assessing certain textile properties has been proposed as part of a TTCP-PTP3 effort to facilitate the exchange of data between countries using different apparatuses. The objective of that study, Operating Assignment 9, is to determine whether values of thermal conductivity and water-vapour permeability of various fabrics are comparable when measured on two different apparatuses: the CORD Sweating Hot Plate (used by Australia and Canada) and the Hoenstein Sweating Hot Plate (used by the United Kingdom and the United States). Several fabric samples were submitted for independent testing by various nations.

Sweating hot plates were developed as research tools to examine questions of combined heat and moisture transport through clothing ensembles rather than as an apparatus for determining fabric characteristics. As such, there was some concern that the material property values obtained with a sweating hot plate may not be sufficiently precise.

The work presented here is an alternative measure to the sweating hot plate approach for determining the relevant material properties. The two apparatuses used in this investigation were specifically designed to measure thermal conductivity and water-vapour permeability and should thus provide an accurate benchmark for comparison of the other methods.

As this is an interim report, no comparison was done of the results obtained to sweating hot plate values.

Introduction

This report describes an independent set of measurements of the properties of several materials being studied in a round-robin evaluation of sweating hot plate apparatuses as part of Operating Assignment 09 of PTP-3. The test results presented here were performed to validate measurements made using a sweating hot plate at the Defence and Civil Institute of Environmental Medicine on behalf of Canada, although it was thought that this information may be of interest to other participants as well.

The apparatuses used in this investigation differ from sweating hot plate apparatuses. Each device was specifically designed to measure either thermal conductivity or water-vapour permeability at steady state involving little interaction with the surrounding environment, allowing the boundary conditions for the tests to be accurately controlled. The simplicity of these devices and test procedures leads to a high degree of confidence in the accuracy of the results. The results obtained with the apparatuses used in this investigation should agree with those of other investigations, since, if they are to be truly meaningful, the results should not depend on the test method or apparatus used, only the established conditions.

The report includes a brief description of the apparatuses used, the expected precision of the results and the results themselves. A brief discussion is presented although no interpretation of the results is offered. Measurements were made in house by the author. Comparison with the sweating hot plate measurements was not formally done.

Method

The following properties were measured for each of the subject materials: thickness, mass per unit area, water vapour resistance and thermal conductivity. The first two measurements were added for internal records as well as to help identify each material, should labelling become confused between investigations. Each of the tests will be described briefly in this section and the results of the tests are reported in the following section. For the thickness, mass per unit area and thermal conductivity measurements, a single sample, typically 30 cm by 30 cm square (±0.2 cm), was cut from each fabric while a separate sample was cut for the water vapour resistance measurement.

Thickness

The thickness of each of the fabrics was measured with a 'Thickness, Compression and Recovery Tester, Model CS-55, Custom Scientific Instruments, Whippany, N.J.'. For materials other than the battings, the pressure plate diameter was 29 mm and the pressure on the fabrics was 1 kPa. For the two batting materials, a 90 mm plate was used with a pressure of 0.167 kPa. The uncompressed thickness of the battings (denoted by a pressure of 0 kPa in the table of results) was estimated by eye using a steel ruler. For the Canadian batting, the thickness was also measured when subjected to the 1 kPa pressure with the smaller plate. The precision of the measurement is estimated to be 0.008 mm which is greater than normally required for most textile applications. Several readings were made over various points in each sample and the readings were averaged.

Mass per unit area

The samples were weighed on an 'AND Electronic Balance, Model FX-400, A&D Company Ltd, Japan'. The area of the samples was computed from the measured length of the sides of the sample to a precision of approximately 0.04 cm^2. The precision of the mass measurement was 0.01 g. The mass per unit area was then computed by dividing the measured sample mass by its area and the uncertainty in this measure is approximately $\pm 0.4\ g/m^2$.

Water Vapour Resistance

Water vapour resistance is defined in this report as 'the mass flow rate of water vapour per unit area per unit vapour pressure difference'. The apparatus used to measure this value was built in house, based on a design developed at TNO [van Beest and Wittgen (1986)]. Most of the fabrics were tested at approximately 50% relative humidity and at room temperature (21° to 23°C). One of the samples (UK-1) was suspected of containing a hydrophilic membrane, so it was measured at several relative humidities, all at room temperature. The reported relative humidity is the average of the two relative humidities from each surface of the sample.

Samples of fabric were held horizontally in the apparatus between a lower surface that is maintained saturated with water and an upper surface that is continuously dried by a desiccated air stream. The humidity at the sample was adjusted by adding spacers to produce known thicknesses of still air above and below the sample. The intrinsic resistance of the apparatus was determined by measuring the resistance of still air layers of known thicknesses and converting the measurements to an equivalent thickness of air as shown in Figure 1. A least-

squares linear regression was applied to the calibration results and the intercept for an air gap thickness of zero was attributed to the apparatus' resistance. This was assigned to the dry surface of the apparatus and was subtracted from each sample's measured value. As water evaporated from the wet surface, it was replenished from water in a graduated pipette. The evaporation rate was measured by timing the movement of the meniscus through the pipette with a stopwatch. The values obtained by this measurement technique are estimated to have an uncertainty (one standard deviation) of approximately 5% of the mean value based on the calibration results. The humidity at each surface of the sample was calculated after the experiment, using the measured and known resistances between the saturated and dry surfaces of the apparatus.

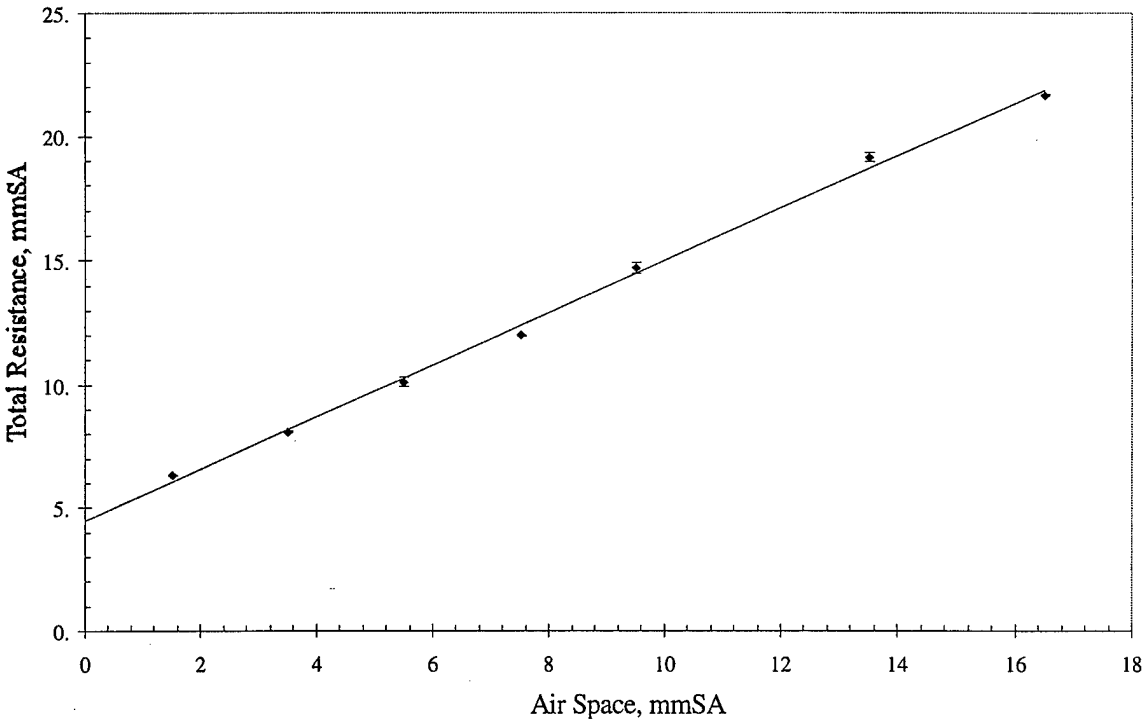

Figure 1. Calibration results of the water vapour permeability apparatus. Total Resistance is the measured water vapour resistance of the Air Space (between the wet and dry surfaces) and the intrinsic apparatus resistance. Error bars represent one standard deviation from the mean but the standard deviation is generally small and the error bars are often obscured by the data point marker.

British sample #1, a shell fabric and batting insulation combination, was measured both as an assembly and as individual components after the layers had been separated. The results for the individual shell fabric and the batting

material are reported as British samples 1a and 1b respectively after the assembly data.

The water vapour resistance was multiplied by the latent heat of evaporation of water (at the wet surface temperature) to convert the mass flow resistance defined above into quasi-heat-flow units specified by ISO.

Thermal Conductivity

The thermal conductivity of each material was measured using a 'Heat Flow Meter Instrument, model FOX400, Lasercomp Inc., Lynnfield, MA'. Fabric samples were placed in this device between two isothermal plates (±0.01°C). The temperature of each plate is specified by the user. The resulting heat flow was measured by thin film heat flux transducers located in the central portion of each plate. The internal calibration of the heat flux transducers (performed by the manufacturer to NIST SRM 1450b) was used which results in a manufacturer's reported accuracy of ±2% for the derived thermal conductivity. For the textiles measured, the distance between the plates was set automatically by the apparatus to a reported accuracy of ±0.0025 cm. Stepper motors moved the bottom plate upwards until force transducers indicated contact between the sample and the plates. The plate separation recorded by the apparatus agreed with the fabric thickness measurement previously described to within the reported precision of either apparatus. A different technique was used for the batting samples. In these two cases, the plate separation was specified *a priori* and the plates automatically compressed the sample to the specified thickness. The thermal conductivity of each batting sample was measured and reported at several thicknesses.

The thermal conductivity of the sample was computed by the apparatus from the measured heat flux, the temperature difference and the plate separation. Calculating thermal resistance from the thermal conductivity and the plate separation is expected to have an uncertainty of approximately ±0.001 m^2K/W.

The samples were measured at three nominal temperatures of 20°, 30°and 45°C although the British batting was also measured at 10°C. For the textiles, the temperatures of the plates were set to 1°C above or below the nominal temperature to keep the resulting heat flux within the measurement range of the apparatus. For the battings, the plates were set to 5°C above or below the nominal temperature to increase the apparatus sensitivity.

Results and Discussion

Table 1 lists the fabric properties of the materials of the round-robin investigation that were obtained by the techniques outlined above. In most cases, the standard deviation of the water vapour permeability is small relative to the mean value, although it is sizeable in a few instances. In particular, measurements of the two Canadian samples showed some variability. Canadian sample #1, a wool felt, was tested 4 times; each test was composed of several measurements. In any given test, the standard deviation of the measurements was less than 10% of the mean value, however, a greater variation was observed between test mean values which gave rise to the ~30% standard deviation quoted in Table 1. It should be noted, however, that the mean value of the water vapour permeability of the Canadian #1 sample would likely be a small component of a typical insulating garment and as such, the observed variability is probably not of much practical importance. For the second Canadian sample (insulating batting between two shell fabrics), the largest uncertainty (~17%) arose when the material was not compressed; other values of the standard deviation were less than 10% of the mean value. This fabric was tested twice at each thickness. The source of the discrepancy is unknown, but battings have been found to be difficult materials to measure.

Direct comparison of the results in Table 1 to those obtained through sweating hot plate measurements may be complicated because of the air flow over the sample specified in the ISO test procedure. With the air flow over the sample, there is a risk that ventilation of the sample will occur, increasing the apparent water vapour permeability and decreasing the apparent thermal resistance. For thin materials, the air flow may not significantly affect the results; however, additional steps will likely be required to ensure that the batting samples do not experience air penetration from the forward edge of the sample.

The air flow may also cause some additional problems not found with the techniques used in this study. The flow over the sweating hot plate will cause the local heat transfer coefficient to vary in the direction of the flow, particularly if the boundary layer over the plate begins at or near the edge of the sample. Since the boundary layer will require an extensive approach to become fully developed, it is unlikely that the test surface will be uniformly exposed to the flow. While this may not be significant to a particular test apparatus due to the relatively small size of the test surface, it could give rise to differences between apparatuses if the test surfaces are located at different points along the developing boundary layer.

The measurement of turbulence in the ISO standard also seems somewhat suspect. Time scales in turbulence for these geometries are small; a rough

calculation indicated that the characteristic time would be as much as a couple of tenths of a second and probably much less. Thus, recording air speed once every several seconds as a measure of turbulence is meaningless and a device that has a response time much less than 1 second is required to accurately capture the flow variability, contrary to what is specified in the standard. Again, this may not be important for standard testing, however, it may be significant if the values obtained are to be compared between apparatuses and if the results are to be used in actual calculations as opposed to beingv simply a standard test value of limited practical significance.

Conclusion

The results recorded in this report provide alternative measurements of the thermal properties of several fabrics for use in the assessment of different sweating hot plate measuring apparatuses used by the participating nations. It is hoped that this data will be useful in subsequent discussions should significant differences arise between different sweating hot plate measurements.

Offering these results as benchmark values may be presumptuous, however, it is thought that the reported values are accurate measures of thermal conductivity and water vapour permeability. It is the author's *opinion* that the techniques used here are superior to that outlined in the ISO standard since they do not employ a rather arbitrarily defined airflow as part of the test procedure. The validity of this opinion, however, remains to be established and discussions on the subject are encouraged.

References

van Beest,C.A.; Wittgen,P.P.M.M.; (1986) A simple apparatus to measure water vapour resistance of textiles, Textile Research Journal, V56(9), 566-568.

Table 1. Measured material properties of the sample fabrics.

Country	Sample	Description	mass/area	Thickness		@Pressure	Thermal Conductivity				plate separation	Water Vapour Permeability		Water Vapour Resistnace		ISO Units	Sample RH	Batting Thickness in WV Apparatus
							at 10C	at 20C	at 30C	at 45C		mean	s.d.	mean	s.d.			
			g/sq.m.	mm	s.d.	kPa	W/mK	W/mK	W/mK	W/mK	mm	g/sq.m.Pa.s		mmSA		sq.m. Pa/W		mm
Australia	A	cam shell fabric, peculiar odour at high humidity	166.3	0.41	0.02	1		0.0234	0.0238	0.0249	0.3	1.71E-04	5.5E-05	1.2	0.4	2.39	48%	
	B	cam shell fabric, a little bit of odour when humid	219.4	0.48	0.02	1		0.0313	0.0318	0.0328	0.4	1.1E-04	4.8E-06	1.7	0.1	3.7	47%	
	C	cam shell fabric	285.4	0.61	0.02	1		0.0372	0.0378	0.0396	0.6	8.4E-05	3.6E-07	2.3	0.3	4.9	47%	
U.K.	1	batting with green shell fabric and scrim	356.1	~35		0	0.0514	0.0550	0.0589	0.0654	35.0	1.1E-05	1.4E-08	17.5	0.1	37.4	62%	15.8
				17.9	1.3	0.167	0.0453	0.0483	0.0515	0.0566	25.0	1.5E-05	8.0E-08	12.9	0.2	27.6	64%	11.8
							0.0376	0.0397	0.0419	0.0455	15.0	2.1E-05	2.5E-07	9.0	0.5	19.4	67%	7.8
							0.0308	0.0320	0.0333	0.0353	5.0	3.7E-05	9.9E-08	5.2	0.1	11.1	71%	3.8
	1a	green shell fabric only										9.0E-05	3.2E-08	2.1	0.0	4.5	49%	
	1b	white backing scrim only										1.9E-04	1.4E-07	1.0	0.1	2.2	49%	
	2	cam wool felt blanket	361.3	4.65	0.1	1		0.0355	0.0370	0.0391	4.7	7.3E-05	1.4E-06	2.6	0.0	5.6	45%	
	3	cam shell fabric, vapour permeable, waterproof	196.1	0.48	0.01	1		0.0295	0.0298	0.0310	0.5	1.3E-04	9.7E-08	1.4	0.0	3.1	93%	
												2.8E-05	1.0E-07	6.8	0.1	14.6	60%	
												2.3E-05	2.2E-07	8.1	0.4	17.4	52%	
Canada	#1	Wool felt blanket-like material	384.6	1.49	0.02	1		0.0315	0.0322	0.0340	1.3	6.3E-05	2.0E-05	3.3	1.2	6.5	54%	
	#2	Insulating batting between 2 shell fabrics	378.7	~12		0		0.0402	0.0425	0.0464	11.9	1.1E-05	1.7E-06	17.8	3.0	37.5	62%	11.8
				8.3	0.5	0.167		0.0361	0.0379	0.0407	7.5	1.2E-05	8.1E-07	16.0	1.1	34.2	63%	7.8
				7.05	0.01	1		0.0336	0.0350	0.0374	5.0	1.8E-05	1.1E-07	10.4	0.2	22.3	66%	3.8
								0.0313	0.0325	0.0346	3.0							

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